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ECONOMICAL AND ENVIRONMENTAL ANALYSES OF THERMAL INSULATION THICKNESS IN BUILDINGS

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Abstract: In Turkey most of the energy demand is imported. Therefore, energy savings obtained from heating applications play an important role in Turkey's economy. Insulation of buildings is an important technology for saving heating energy and for a sustainable development. Despite this fact, insulation in buildings is still uncommon. The insulation materials that are commonly used have standard sizes, so one must choose between the available sizes. In this study, two common materials namely glass wool and rock wool were used. Heating loads were calculated by means of the degree-day method. For the economical analysis, the optimum insulation thickness values were calculated by life cycle method, but naturally these values did not correspond with the available thicknesses. Also, an environmental analysis was performed by using these standard and optimum values. Feasibility of these materials for commercially available sizes and for different fuel types was assessed. Two different locations were chosen. Izmir was chosen as a city representing the milder climate of the coasts and for the colder climates of the interiors Ankara was chosen. It was found that for cheap heating systems such as systems using coal the payback periods become too long and sometimes even longer than the lifetime of the insulation material. Yet, when environmental issues are considered insulation should in any case be applied and promoted by governments.
Keywords: Optimum insulation thickness, Life-cycle analysis, Energy conversation, Environmental impact.

YAPILARDA ISI YALITIM KALINLIĞININ EKONOMİK VE ÇEVRESEL ANALİZİ

Özet: Türkiye enerji ihtiyacının büyük bir bölümünü ithal etmektedir. Bu nedenle, ısıtma uygulamalarından elde edilen enerji tasarrufu Türkiye ekonomisinde büyük bir rol oynamaktadır. Yapıların yalıtılması, ısıtma enerjisinden tasarruf etmek ve sürdürülebilir bir gelişme için önemli bir teknolojidir. Bu gerçeğe rağmen, Türkiye'de yapıların yalıtılması hala yaygın bir şekilde geliştirilememiştir. Yalıtım malzemeleri genellikle standart boyutlara sahiptir ve bu nedenle mevcut boyutlardan biri seçilmek zorundadır. Bu çalışmada, yalıtım malzemesi olarak, yaygın bir şekilde kullanılan cam yünü ve taş yünü kullanılmıştır. Isı yükleri derece gün metodu kullanılarak hesaplanmıştır. Ekonomik analizde ise optimum yalıtım kalınlıkları malzeme ömrü analizi yöntemi ile hesaplanmış, ancak bu değerler standart yalıtım kalınlıkları ile uyuşmamıştır. Aynı zamanda, bu standart ve optimum yalıtım kalınlıkları için bir çevresel analiz yapılmıştır. Ticari olarak üretilen bu malzemelerin ekonomik analizi farklı yakıt türleri için değerlendirilmiştir. Şehir olarak; ılıman ilkime sahip İzmir ve daha soğuk iklime sahip Ankara illeri seçilmiştir. Kömür gibi ucuz yakma sistemlerinin kullanılması durumunda yalıtım için geri dönüş süreleri çok uzun olduğu hatta bazı durumlarda yalıtım malzemesinin ömründen uzun çıktığı bulunmuştur. Buna rağmen çevresel etkiler dikkate alındığında her durum için yalıtım gereklidir ve hükümetler tarafından teşvik edilmelidir.
Anahtar Kelimeler: Optimum yalıtım kalınlığı, Malzeme ömrü analizi, Enerji korunumu, Çevresel etki.

NOMENCLATURE

A_s	annual savings	*Greek letter*	
C	cost [\$ kg^{-1}, \$ m^{-3}, \$ kW h^{-1}]	η_S	Efficiency of space heating system
DD	degree-days [^{o}C-days]	ρ	Density of insulation materials [kg/m^3]
E_A	annual heating energy [J m^{-2} year^{-1}]	*Subscripts*	
ES	energy savings of 10 years [\$ m^{-2}]	A	annual
g	inflation rate [%]	f	fuel
h	convection heat transfer coefficient [W/m^{2}K]	s	system
i	interest rate [%]	i	inside
k	thermal conductivity [W m^{-1} K^{-1}]	I	insulation material
L	thicknesses of wall components [m]	ip	inlet plaster

LCCA	life-cycle cost analysis	o	outside
LHV	lower heating value of the fuel [J/kg, J/m^3, J/kW h]	op	outlet plaster
m_{fA}	annual fuel consumption [kg m^{-2}year^{-1}, m^3 m^{-2}year^{-1}, kW h m^{-2}year^{-1}]	opt	optimum
PP	payback period [years]	t	total
PW	present worth factor	t_{ins}	total heating costs of the insulated building
q	heat loss [MJ m^{-2} year^{-1}]	t_o	total heating costs of the non insulated building
r	interest rate adjusted for inflation	t_w	total wall excluding insulation material
R	thermal resistance [m^2 K W^{-1}]	w	wall material
T_b	base temperature [^{o}C]	x	insulation thickness [m]
T_0	mean daily temperature [^{o}C]	*Superscripts*	
U	overall heat transfer coefficient [W m^{-2} K^{-1}]	*	standart sizes insulation material
ins	insulation		

INTRODUCTION

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. The importance of energy in economic development is recognized universally, and historical data verify that there is a strong relationship between the availability of energy and economic activity. Although in the early seventies, after the oil crises, the concern was on the cost of energy, during the past two decades, the risk and reality of environmental degradation have become more apparent. The growing evidence of environmental problems is due to a combination of several factors, since the environmental impact of human activities has grown dramatically. This is due to the increase of the world population, energy consumption and industrial activities (Ocak et al., 2004). Excessive use of fossil fuels causes air pollution and is accepted as the main cause of global warming.

A few years ago, most environmental analysis and legal control instruments concentrated on conventional pollutants, such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), particulates and carbon monoxide (CO). Recently however, environmental concern has extended to the control of hazardous air pollutants, which are usually toxic chemical substances that are harmful even in small doses, as well as to other globally significant pollutants such as carbon dioxide (CO_2) (Dincer, 1998).

Achieving solutions to the environmental problems that humanity faces today requires long term potential actions for sustainable development. In this respect, energy resources appear to be one of the most efficient and effective solutions (Ocak et al., 2004).

It can be seen from Table 1. that about 30 % of the energy consumption is accounted for by buildings. Energy consumption in buildings comprises various applications such as heating, lighting, water heating etc. Heating accounts for approximately 40% of energy consumption in buildings (Bolattürk, 2006; Ozkahraman and Bolatturk, 2006). An important method of reducing energy consumptions and environmental pollution of buildings is applying insulation.

Table1. Distribution of energy consumption in various sectors versus the years, in % (Bolattürk, 2006).

Year	Industry	Buildings	Transportation	Agriculture	Other
1995	35.80	34.41	21.32	5.49	2.98
1999	38.96	33.75	19.82	5.11	2.36
2003	42.24	31.44	19.22	5.08	2.02
2007	45.47	29.25	18.55	4.99	1.74

The annual heating and cooling requirements of buildings in different regions can be obtained by means of the heating degree-days concept which is the well known and simplest method. Despite its simplicity, accurate results can be obtained with the degree-day method for most houses and single-zone buildings. This method becomes too crude and unreliable for buildings that experience large hourly and daily fluctuations, such as crowded office buildings. A dynamic method that considers solar radiation, infiltration, the thermal inertia of the building, and the variation of heat transfer coefficient and equipment efficiency needs to be used in such cases (Bolattürk, 2006; Çengel, 1998; Buyukalaca et al., 2001). The accuracy of degree-day method may be improved by using different base temperatures in different climate zones. However, for simplicity and ease of comparison, only one base temperature was used in this study to determine the optimum insulation thickness of external walls for selected cities.

In literature, there are many studies on different aspects of building insulation. Hasan (1999) used life-cycle cost analysis to determine optimum insulation thicknesses. The results showed that 10 year lifetime savings up to

21 $/m^2 of wall area are possible for rock wool and polystyrene insulation. He determined payback periods of 1–1.7 years for rock wool and 1.3–2.3 years for polystyrene insulation depending on the type of wall structure. Mohsen and Akash (2001) investigated the energy saving measures in building insulations for different materials, such as polystyrene, rock wool, and air gap. They found that energy savings up to 77% could be achieved when polystyrene is used for both wall and roof insulation. Çomaklı and Yüksel (2003) calculated the optimum insulation thicknesses for the coldest cities of Turkey considering only coal as the fuel. They found that the saving in the cold cities may be as much as 12.13 $/m2 of wall area over a lifetime of 10 years. Also, they investigated the environmental impact of thermal insulation thickness in buildings. They determined that CO_2 emission amounts decreased 50% by means of optimum insulation thickness use and other energy saving methods in buildings (Çomaklı and Yüksel, 2004). Jaber (2002) concluded that space heating load could be reduced by about 50% by adding economic viable insulation material to ceilings and walls. Al-Sallal (2003) compared polystyrene and fiberglass roof insulations in warm and cold climates and found that the payback period in cold climates is shorter than that in warm climates. Al-Khawaja (2004) investigated determination and selecting the optimum thickness of insulation for buildings in hot countries by accounting for solar radiation. He found that wallmate insulation show the best performance for houses in Qatar. Dombaycı et al. (2006) investigated optimization of insulation thickness for external walls using different energy-sources. They obtained optimum by using coal as the energy source and expanded polystyrene as the insulation material. When the optimum insulation-thickness is used, the life cycle saving and payback period are 14.09 $/m^2 and 1.43 years, respectively. Ozkahraman and Bolatturk (2006) investigated the use of tuff stone cladding in buildings for energy conservation. It was shown that considerable energy savings can be achieved by using tuff stone for facing buildings in cold climate zones such as Isparta region. The cost of installing tuff stone panels for facing buildings will be paid back in four years by savings in heat energy. Dombaycı (2007) investigated the environmental impact of optimum insulation thickness. In the calculations, coal was used as the fuel source and the expanded polystyrene as the insulation material. He found that when the optimum insulation thickness is used, the emissions of CO_2 and SO_2 are decreased by 41.53%. Sisman et al. (2007) investigated optimum insulation thicknesses of the external walls and ceiling on buildings for different regions of Turkey. Also, they found correlations of optimum insulation thicknesses in terms of degree days.

In buildings heat is lost by 40% of external wall, 30% window, 17% door and ventilation, 7% of roof and 6% floor. The insulation materials that are commonly used have standard sizes, so one must choose between the available sizes. In this study, two common materials namely glass wool and rock wool were used. The optimum insulation thickness values were calculated, but naturally these values did not correspond with the available thicknesses. An environmental impact analysis was performed by using these standard and optimum values. Feasibility of these materials for commercially available sizes and for five different energy sources (coal, fuel oil, electricity, natural gas and LPG) was assessed. Environmental impact of electricity was not evaluated. Although heating with electricity seems to be a method with no emissions, one must keep in mind that electricity production has an important impact on environment during its production. But this impact was not analyzed in this study. Two different locations were chosen. Izmir was chosen as a city representing the milder climate of the coasts and for the colder climates of the interiors Ankara was chosen. All the unit prices, lower heating values and efficiencies of heating systems that were used in the analysis are given in Table 2. According to these analyses an optimum available product was determined.

Table 2. Properties of fuels and heating systems (www.tki.gov.tr;http://www.dosider.org; www.poas.com.tr; www.tupras.com.tr;www.tedas.gov.tr).

Fuel	Price	LHV	η_s (%)
Coal (Soma)	0,128 $/kg	23,023 x 10^6 J/kg	70
Natural gas	0,331 $/m^3	34,534 x 10^6 J/m^3	90
Fuel-oil	0,9595 $/kg	40,604 x 10^6 J/kg	82
LPG	1 $/kg	46,046 x 10^6 J/kg	90
Electricity	0,135 $/kW h	3,599 x 10^6 J/kWh	99

BUILDING MATERIALS AND STRUCTURE OF EXTERNAL WALLS

Generally, sandwich type walls are used in insulation applications. In this study, the calculations were carried out for a sample wall as given in Figure 1.

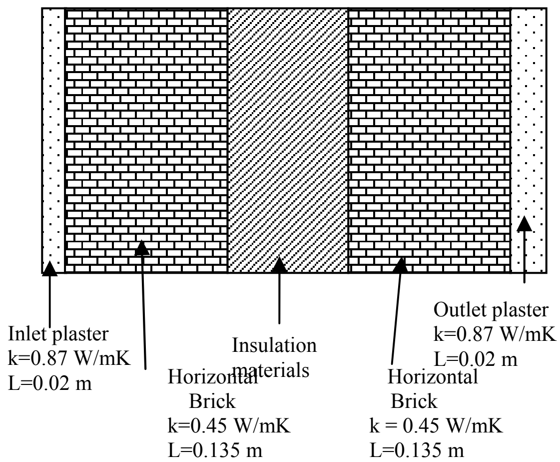

Figure 1.Cross-sectional view of the external walls.

This sample wall comprises two layers of horizontal bricks, in between which the insulation material is placed. Both the indoor and outdoor faces of this wall are covered with a layer of plaster.

HEATING LOAD

Heat losses from a building at steady-state are computed as losses through walls and ceilings, plus ventilation and air infiltration.

Air ventilation and infiltration are not affected by wall insulation, while heat losses through walls decrease with increasing resistance or decreasing conductance. Hence, only wall losses will be considered in the insulation thickness optimization analysis that will follow.

The heat loss per unit area of external wall is

$$q = U(T_b - T_o) \tag{1}$$

where U is the heat-transfer coefficient. T_b is base temperature and T_0 is mean daily temperature and are given in Table 3 for Izmir and Ankara.

Table 3. Degree days for a base temperature of 20 °C and mean daily temperatures for Ankara and Izmir (Buyukalaca et al., 2001; TS 825, 1999).

City	Degree days (°C days)	Mean daily temperature (°C)
Izmir	1583	0
Ankara	3214	-12

The annual heat loss per unit area in respect of degree-days can be obtained from

$$q_A = 86400\,DD\,U \tag{2}$$

where DD is the degree-days. The annual energy requirement can be calculated by dividing the annual heat loss to the efficiency of the heating system η_s ,

$$E_A = \frac{86400\,DD\,U}{\eta_s} \tag{3}$$

The wall conductance U for a typical wall that includes a layer of insulation is given by

$$U = \frac{1}{R_i + R_w + R_{ins} + R_o} \tag{4}$$

where R_i and R_0 are the inside and outside air film thermal resistances, respectively. R_w is total thermal resistance of the composite sandwich wall materials without the insulation, and R_{ins} is the thermal resistance of the insulation layer, which are respectively

$$R_w = \frac{1}{h_i} + \frac{L_{ip}}{k_{ip}} + \frac{L_{hb}}{k_{hb}} + \frac{L_{hb}}{k_{hb}} + \frac{L_{op}}{k_{op}} + \frac{1}{h_o} \tag{5}$$

$$R_{ins} = \frac{x}{k} \tag{6}$$

where x and k are the thickness and thermal conductivity of the insulation material, respectively. If R_{tw} is the total wall resistance excluding the insulation layer resistance, Eq. (4) can be written as

$$U = \frac{1}{R_{tw} + R_{ins}} \tag{7}$$

$$R_{tw} = R_w + \frac{x_{ins}}{k_{ins}} \tag{8}$$

As a result, the annual heating load is then given by

$$E_A = \frac{86400\,DD\,U}{\left(R_{tw} + \frac{x}{k}\right)\eta_s} \tag{9}$$

and the annual fuel consumption is

$$m_{fA} = \frac{86400\,DD}{\left(R_{tw} + \frac{x}{k}\right) LHV\,\eta_s} \tag{10}$$

where LHV is lower heating value of the fuel given usually in J/kg, J/m^3 or J/kW h depending on the fuel type.

LIFE-CYCLE ANALYSIS AND OPTIMIZATION OF INSULATION THICKNESS

The life-cycle cost analysis (LCCA) involves the analysis of the costs of a system or a component over its entire lifetime. Life-cycle cost analysis used in this study computes the total cost of heating over the lifetime of the insulation material which was taken as 10 years. The total heating cost over a lifetime of N years is converted to present value by multiplying it by the present worth factor, PW. The PW value, which includes the interest rate i and the inflation rate g is adjusted for inflation (Bolatturk, 2006). i and g are taken as 16%, 8.7%, respectively (www.tcmb.gov.tr).

The interest rate adapted for inflation rate r is given by:

if $i > g$ then

$$r = \frac{1-g}{1+g} \tag{11}$$

if $i < g$ then

$$r = \frac{g - i}{1 + i} \quad (12)$$

and

$$PW = \frac{(1 + r)^N - 1}{r(1 + r)^N}$$

where N is the lifetime, which is taken to be 10 years.

The annual energy cost of heating per unit area, C_A, can be defined as

$$C_A = \frac{86400\, DD\, C_f}{\left(R_{tw} + \frac{x}{k}\right) LHV\, \eta_s} = m_{fA}.C_f \quad (13)$$

where, C_f is the fuel cost in \$/kg, \$/m^3, or \$/kW h depending on the fuel type.

The cost of insulation is given by

$$C_{ins} = C_I\, x \quad (14)$$

where, C_I is the cost of insulation material in \$/m^3 and x is the insulation thickness in m. Properties and cost of glass wool and rock wool insulation materials is given in Table 4.

Table 4. Properties and cost of insulation materials.

Thickness (m)	Glasswool	Rockwool	Glasswool (ρ = 12 kg/m^3)	Rockwool (ρ = 52 kg/m^3)
	Cost (\$/m^3)		R (m^{2}K/W)	
0.03	108.1081	148.6486	0.75	0.75
0.04	104.7297	143.5811	1.0	1.0
0.05	101.3514	129.7297	1.25	1.25
0.06	96.84685	128.3784	1.50	1.50
0.075	91.89189	-	1.875	-
0.08	-	125.8446	-	2.0
0.1	88.51351	120.2703	2.5	2.5
0.12	-	113.7387	-	3.0

As a result, the total heating cost of the insulated buildings is given by

$$C_t = C_A\, PW + C_I\, x \quad (15)$$

The optimum insulation thickness is obtained by minimizing Eq. (15). Hence, the derivative of C_t with respect to x is taken and set equal to zero from which the optimum insulation thickness x_{op} is obtained as

$$x_{op} = 293.94 \left(\frac{DD\, C_f\, k\, PW}{LHV\, C_I\, \eta_s} \right)^{1/2} - k\, R_{tw} \quad (16)$$

From Eq. (16), it can be seen that optimum insulation thickness depends on degree-days, fuel cost, insulation material cost, *PW* value, and fuel, wall and insulation material properties.

Then, pay-back period, *PP* is calculated by solving the following equation for *PP*:

$$\frac{C_{ins}}{A_s} = \frac{(1 + r)^{PP} - 1}{r(1 + r)^{PP}} \quad (17)$$

where, C_{ins}/A_s is the simple pay-back period and this value does not take interest rate into account. A_s is the amount of the annual savings obtained by insulation.

Energy savings (\$/m^2) obtained during the lifetime of insulation material can be calculated as follows:

$$ES = C_{to} - C_{tins} \quad (18)$$

where, C_{to} and C_{tins} are the total heating costs of the building when insulation is not and is applied, respectively.

Energy savings can be expressed as % by the following equation:

$$\frac{ES}{C_{to}} \times 100 \quad (19)$$

CALCULATION OF COMBUSTION PROCESSES

In buildings, increasing the insulation thickness reduces heat loss. Moreover, the fuel consumption and air pollution are brought down.

Chemical combinations, mass fractions and chemical formulas of coal, fuel oil and natural gas, LPG are given in Table 5 and Table 6 respectively.

Table 5. Chemical combinations, mass fractions and chemical formulas of coal and fuel oil (Erbatur and Erbatur, 1982; Elektrik İşleri Etüt İdaresi Genel Müdürlüğü, 1997).

	Coal	Fuel oil
C (%)	85.01	87.75
H (%)	5.19	10.49
O (%)	8.27	0.64
N (%)	1.21	0.28
S (%)	0.32	0.84
Chemical formula	$C_{7.078}H_{5.149}O_{0.517}S_{0.01}N_{0.086}$	$C_{7.3125}H_{10.407}O_{0.04}S_{0.026}N_{0.02}$

Table 6. Chemical combinations, mass fractions and chemical formulas of natural gas and LPG (Çoban, 2006; http://www.petrol.itu.edu.tr).

	Natural gas	LPG
CH_4 (%)	91.22	-
C_2H_6 (%)	5.9	-
C_3H_8 (%)	0.06	30
C_4H_{10} (%)	0.02	70
CO_2 (%)	1.7	-
N_2 (%)	1.1	-
Chemical formula	$C_{1.05}H_4O_{0.034}N_{0.022}$	$C_{3,7}H_{4,1}$

Now consider the following combustion equation of fuel having the general chemical formula $C_aH_bO_dS_eN_f$

$$C_aH_bO_dS_eN_f + \alpha.X.(O_2 + 3.76N_2) \rightarrow a.CO2 + \left(\frac{b}{2}\right).H_2O + Y.O_2 + e.SO_2 + ZN_2 \quad (20)$$

The constants *X*, *Y* and *Z* are calculated from the oxygen balance formulas given in (21), (22) and (23), respectively:

$$X = a + \left(\frac{b}{4}\right) + e - \left(\frac{d}{2}\right) \quad (21)$$

$$Y = (\alpha - 1)\left(a + \frac{b}{4} + e - \frac{d}{2}\right) \quad (22)$$

$$Z = 3.76\alpha\left(a + \frac{b}{4} + e - \frac{d}{2}\right) + \frac{f}{2} \quad (23)$$

In (20), *NOx* and *CO* emissions are neglected. The emission rate of combustion products resulting from the burning 1 kg of fuel can be calculated by (Hasan, 1999; Abdallah and Ismail, 2001)

$$M_{CO2} = \frac{a.CO_2}{M} \equiv kg\,CO_2 / kg\ fuel \quad (24)$$

$$M_{SO2} = \frac{e.SO_2}{M} \equiv kg\,SO_2 / kg\ fuel \quad (25)$$

The total emission of CO_2 and SO_2 could be calculated if the right hand side the above expressions by m_{fA}, which is total burned fuel within *DD*. The equations of emission are given in

$$M_{CO2} = \frac{44.a}{M}.m_{fA} \quad (26)$$

$$M_{SO2} = \frac{64.e}{M}.m_{fA} \quad (27)$$

M is the weight of mol for fuel which can be calculated using

$$M = 12.a + b + 16.d + 32.e + 14.f \quad \text{kg/kmol}$$

RESULTS

Increasing the insulation thickness of a building decreases the heat loss of a building. But, increasing insulation thickness means that you have to invest more money. Total cost of heating consists of two cost parameters; fuel and insulation costs. Insulation materials used, all have a certain lifetime. Therefore, after a certain value of insulation thickness, although the fuel cost still continues to decrease; this decrease is not enough for the compensation of the increased insulation cost. So, there is a thickness value which is an economically optimum.

The more of a product you buy, the less you pay for its unit amount. This rule applies for insulation materials as well. The thicker insulation materials have lower unit thickness costs. In this study the optimum insulation thicknesses corresponding to the unit prices of the standard insulation material sizes were calculated by equation (14). The calculations were made for two insulation materials, five fuel types and for two locations.

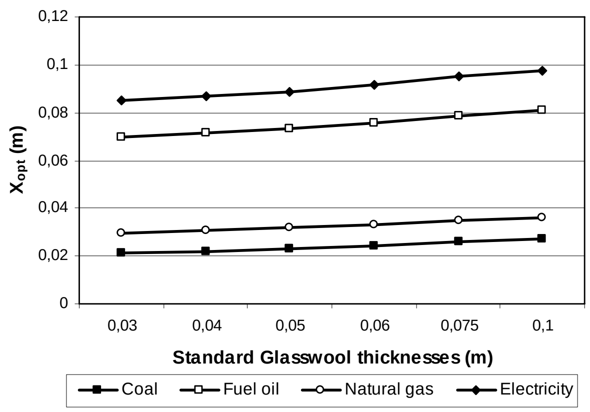

Figure 2. Optimum insulation thickness versus standard glasswool thicknesses for Izmir.

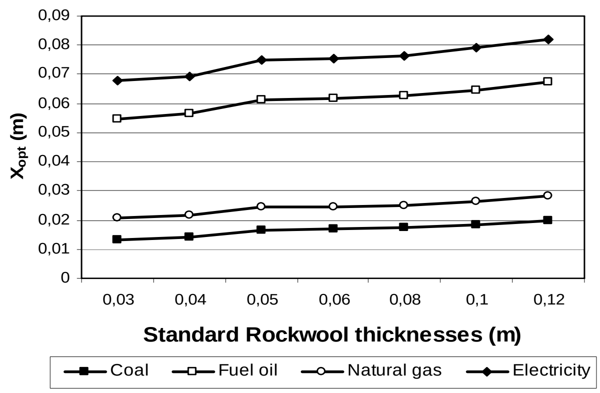

Figure 3. Optimum insulation thickness versus standard rockwool thicknesses for Izmir.

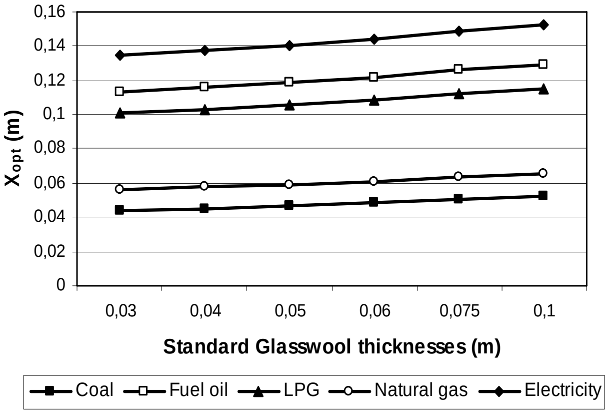

Figure 4. Optimum insulation thickness versus standard glasswool thicknesses for Ankara.

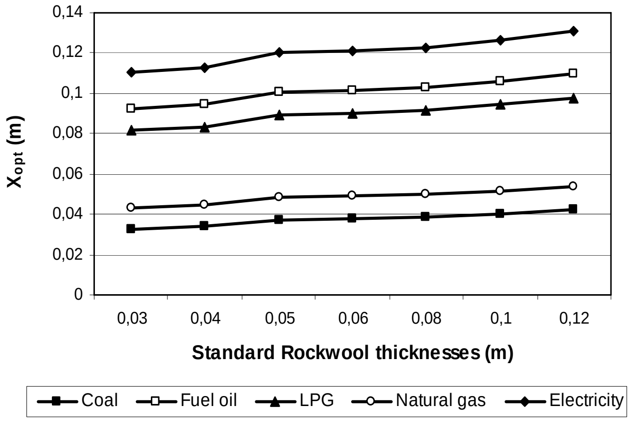

Figure 5. Optimum insulation thickness versus standard rockwool thicknesses for Ankara.

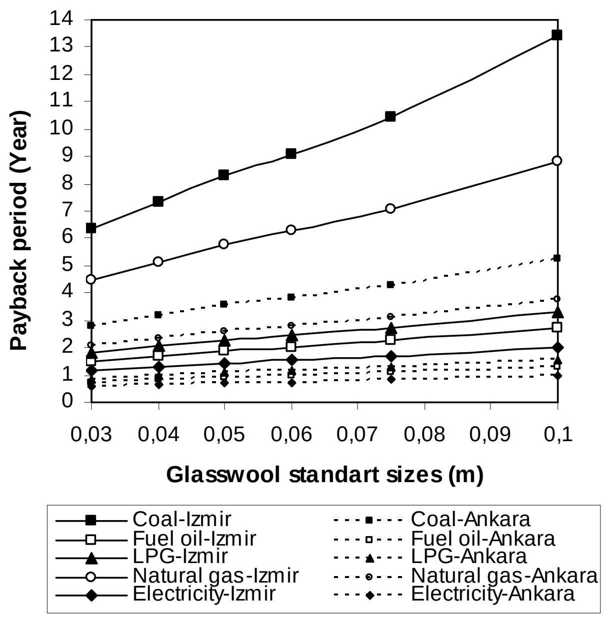

Figure 6. Payback periods versus glasswool standard sizes for Izmir and Ankara.

It can be seen from Figures (2-5) that the optimum insulation thicknesses change by increasing the insulation material thicknesses due to the decrease in the unit cost of the materials.

It is important to note that the standard thicknesses in the x axes of these figures actually do not represent sizes but unit prices. Therefore the optimum values found are actually the values corresponding to that unit price. Generally, the calculated optimum thickness values differ considerably from the available sizes. The energy savings (ES) obtained and payback periods for each of the available standard sizes were calculated from equations (18) and (17) respectively and were given in Figures (6-9).

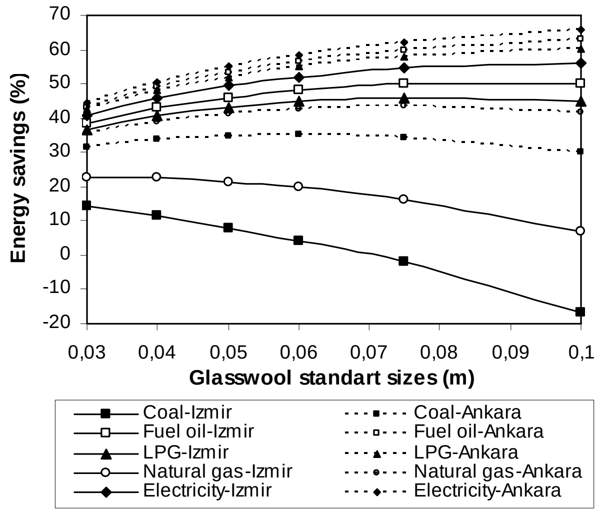

Figure 7. Energy savings versus glasswool standard sizes for Izmir and Ankara.

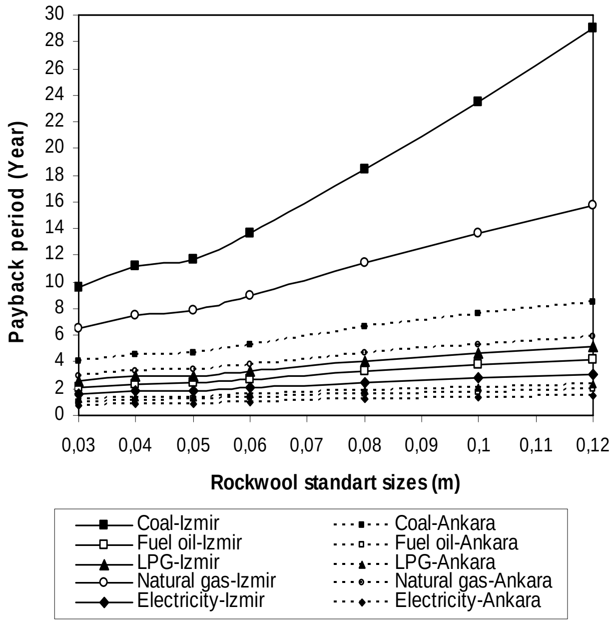

Figure 8. Payback periods versus rockwool standard sizes for Izmir and Ankara.

The payback periods and energy saving rates are very important parameters that have to be considered when choosing the best insulation option. The size of insulation that yields the highest amount of energy saving for different fuel types were given in Table 7.

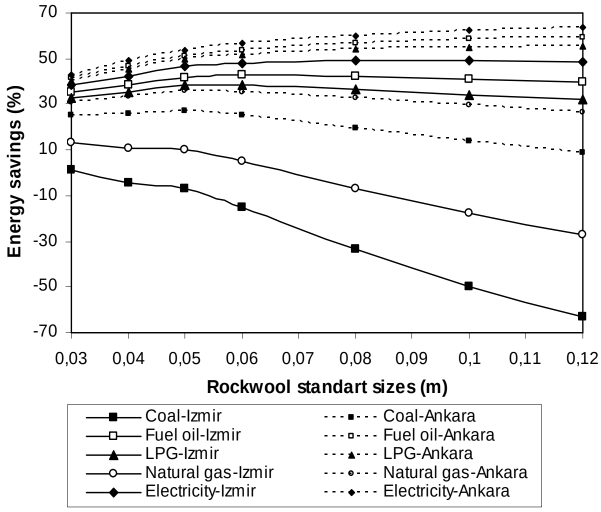

Figure 9. Energy savings versus rockwool standard sizes for Izmir and Ankara.

Table 7. x^*_{opt} values corresponding to standard values of insulation material sizes.

Insulation material	Fuel type	x^*_{opt} (m) for Izmir	x^*_{opt} (m) for Ankara
Glasswool	Coal	0.03	0.06
	Fuel oil	0.1	0.06
	LPG	0.075	0.1
	Natural gas	0.03	0.075
	Electricity	0.1	0.1
Rockwool	Coal	Insulation unnecessary	0.05
	Fuel oil	0.06	0.12
	LPG	0.05	0.1
	Natural gas	0.03	0.05
	Electricity	0.1	0.12

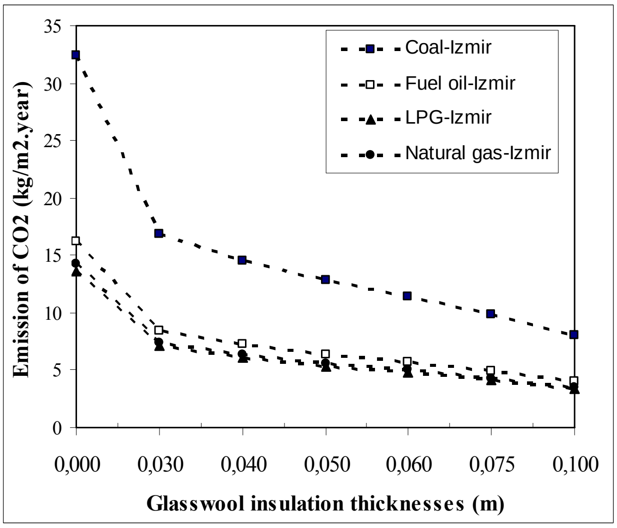

Figure 10. Emission of CO_2 versus glasswoll insulation thicknesses for Ankara.

As it is mentioned earlier nowadays exhaust gas emissions are an environmental problem. Increasing the insulation thickness of a building decreases the pollutant emission into atmosphere, but may not be economical. Therefore, insulation application to external wall of a building must be feasible both economically and environmentally. CO_2 emissions versus standard thicknesses of glasswool and rockwool were shown in Figures (10- 13).

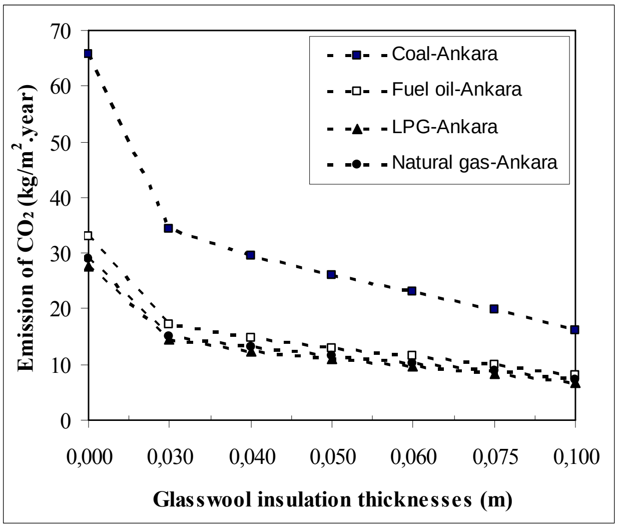

Figure 11. Emission of CO_2 versus glasswoll insulation thicknesses for Izmir.

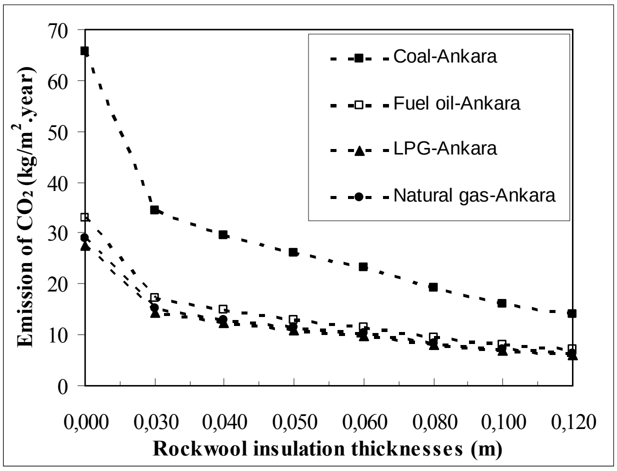

Figure 12. Emission of CO_2 versus rockwoll insulation thicknesses for Ankara.

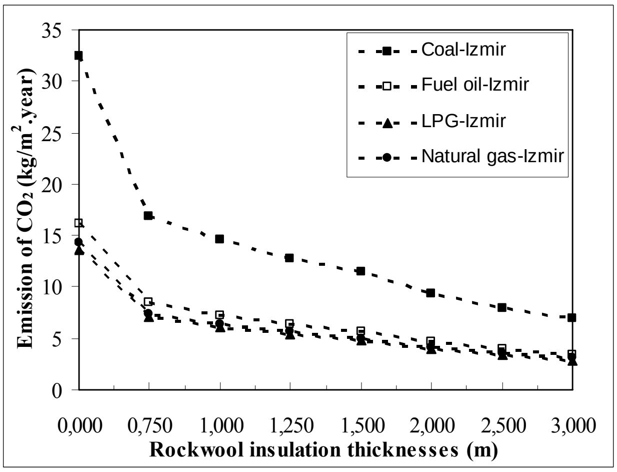

Figure 13. Emission of CO_2 versus rockwoll insulation thicknesses for Izmir.

Naturally, increasing the insulation thicknesses decreases CO_2 emissions. If we apply a 0.06 m glasswool insulation in Ankara which was found to be the optimum when coal is burned, the CO_2 emission decreases by approximately 35%.

CONCLUSIONS

According to the results obtained, insulation becomes more necessary if you are in a colder climate and using a more expensive heating system. In Ankara for all of the heating systems the calculated energy savings in % are greater than that of Izmir's. In this study, cooling loads were neglected. Izmir has 847 cooling degree days annually for a base temperature of 20 ^{o}C. It is obvious that insulation will be economically more feasible for Izmir if cooling is also taken into account. Otherwise, for cheap heating systems such as systems using coal the payback periods become too long and sometimes even longer than the lifetime of the insulation material. But this is only the economical aspect of the issue. In any case insulation means less fuel consumption therefore less emission. Considering this all the governments should promote ways of decreasing energy use including insulation. It is difficult to persuade people to apply insulation to their buildings for the sake of environment so it should be made economically feasible.

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